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## **From undernutrition to overnutrition: the evolution of overweight and obesity among young men in Switzerland since the 19th century**

Staub, Kaspar ; Bender, Nicole ; Floris, Joël ; Pfister, Christian ; Rühli, Frank J

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## Original Article

# From Undernutrition to Overnutrition: The Evolution of Overweight and Obesity among Young Men in Switzerland since the 19th Century

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## Abstract

**Objective:** The global obesity epidemic continues, new approaches are needed to understand the causes. We analyzed data from an evolutionary perspective, stressing developmental plasticity. **Methods:** We present diachronical height, weight, and BMI data for 702,902 Swiss male conscripts aged 18–20 years, a representative, standardized and unchanged data source.

**Results:** From 1875 to 1879, the height distribution was slightly left-skewed; 12.1% of the conscripts were underweight, overweight and obesity were rare. The BMI-to-height relationship was positive but not linear, and very short conscripts were particularly slim. Since the 1870s, Swiss conscripts became taller, a trend that markedly slowed in the 1990s. In contrast, weight increased in two distinct steps at the end of the 1980s and again after 2002. Since 2010, BMI did not increase but stabilized at a high level. **Conclusions:** The body of young men adapted differently to varying living conditions over time: First, less investment in height and weight under conditions of undernutrition and food uncertainty; second, more investment in height under more stable nutritional conditions; third, development of obesity during conditions of plateaued height growth, overnutrition, and decreasing physical activity. This example contributes to the evaluation of hypotheses on human developmental plasticity.

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## Introduction

Obesity has been a major public health issue worldwide and an important contributor to the global burden of chronic disease and disability for decades [1, 2]. Obesity is associated with several deleterious outcomes, such as type 2 diabetes, heart disease, depression, increased all-cause mortality, and reduced life expectancy [3–5]. In 2014, 1.9 billion adults worldwide were overweight, and it has been projected that these numbers will continue to increase until the year 2030 [6]. In Switzerland, 41% of the adult population and 19% of children and juveniles are currently overweight or obese [7]. Obesity and its associated comorbidities were responsible for 11% of the Swiss healthcare expenditures in 2006, representing a considerable economic and public health burden [8]. Efforts to control the epidemic of obesity by the World Health Organization consist of a range of long-term measures, including primary prevention, weight maintenance, management of complications, and weight loss [1]. However, the global obesity epidemic continues despite these measures, indicating that new approaches are needed to understand not only how humans are becoming more obese but also why.

In the past few decades, attempts have been made to explain the human susceptibility to obesity from an evolutionary perspective [9–12]. The aim of evolutionary investigations of human obesity is to understand the underlying ultimate causes of this trait and to gain insight into novel approaches to obesity prevention and control. While several hypotheses have focused on the evolution of human fat tissue at an early stage of human evolution, several other hypotheses have been formulated to explain the variance in human obesity between and within modern human populations. One of the first was the ‘thrifty gene’ hypothesis, which explained the selection of gene variants that are advantageous in periods of famine but at the same time predispose humans to obesity and related health issues in modern times of plenty [13]. This hypothesis has been debated, and alternative explanations have been formulated, such as the ‘developmental origins’ hypothesis, which emphasizes epigenetic and other maternal effects in the pre- and postnatal period of life as a ‘fine-tuning’ mechanism to adapt to a predicted environment [14]. This short-term adaptability to fast changes in the environment is well described in many animal species [15] and has also been demonstrated in human populations [16].

Hypotheses on the evolutionary origins of human adiposity are primarily based on animal studies or theoretical considerations, and human data to test them, especially historical data, are sparse. Because weight measurement and personal scales were uncommon before the 1880s [17, 18], there are only few studies assessing long-term trends in BMI distribution in large human populations [19] or changes in the BMI to height relationship [20–23]. In this study, we present BMI data of Swiss male conscripts, a representative, standardized and unchanged data source spanning the past 140 years. We analyze temporal changes in height, weight, and BMI from 1875 to 2014 and use these data to explore if historical events that influenced food security and abundance in Switzerland had an impact on the BMI of young Swiss men in the same time period or at the time of birth 19 years before.

The present paper contributes to the understanding of short-term (historical) developments of height and weight in a male human population during the transition from the 19th century, a time of food uncertainty, to a modern, Western society. This knowledge can inform our understanding of human developmental plasticity and may therefore contribute to the critical evaluation of hypotheses on human short-term adaptability to changes in living standards, improved disease environment, and food availability and quality.

## Subjects and Methods

### *Conscript Data in Public Health Research*

Finland, Norway, Denmark, Austria, and Switzerland are currently the only countries in Western Europe that continue to rely on full, regular conscription [24]. The anthropometric data collected during conscription yield an annual picture of the anthropometric health status of young men at a prescribed age [25]. Despite being limited to young male populations, the anthropometric status of conscripts is a particularly valuable tool for public health research for two reasons: first, being obese in adolescence increases the risk of being obese as an adult; and second, the morbidity and mortality risks associated with obesity in men in particular increase with age [26].

### *The Swiss Conscription Process*

Since 1875, all 19-year-old male Swiss citizens have been conscripted for military duty and undergo a medical examination for military fitness [27]; this examination was and still is based on detailed standardized rules and instructions [28]. The medical commission maintained annual detailed control books containing measurements for each conscript [29]. The height and weight measurement procedure has remained unchanged over time, which further assures the validity and comparability of the analyzed datasets. The height and weight of each conscript while in underpants, including those who subsequently received an exemption, were measured by two physicians based on specific measurement regulations and identical standards that did not change over time. By regulation, weight was only measured from 1875 to 1879 and again after 1932.

The mandatory, multiple-day recruitment of the Swiss Armed Forces was renewed and expanded in 2004 [30, 31]. The regulations still specify that all young men are summoned for conscription during the year in which they turn 19. However, conscription either before or after this year is possible upon request. The assessment still collects data on anthropometric status (measured height and weight, rounded to integers) as well as other data. These assessments, which are mandatory for every conscript regardless of if they subsequently receive a deferral or an exemption, are conducted under professional medical supervision at six dedicated conscription centers (Lausanne, Sumiswald, Windisch, Rüti, Mels, and Monte Ceneri) that have identical qualitative standards for technical equipment and organizational structures (Verordnung über die Rekrutierung (VREK), 511.11, Art. 3 and Art. 9).

### *Data Sources*

By systematic inquiries at all of the cantonal State Archives, we located each control book containing the medical examinations for the 1875–1879 conscription years that existed in Switzerland. An existing dataset from an earlier publication [32] (which included full cohorts from the cantons Basel-Stadt, Basel-Land, Bern, Zürich) was thereby substantially expanded (by a factor of 2.7 for 1875–1879 and by 1.2 for the 1930s) by the addition of full conscription cohorts from three other cantons: Geneva, Valais, and Solothurn (various cantons did not archive the control books of the medical examination of conscripts until recently). Thus, the 1875–1879 dataset used in this study contains every surviving weight measurement taken during conscription in Switzerland at that time. Overall, the regional selection of our historical data is driven by data existence (1875–1879) or availability (the 1930s). However, to improve reliability, our selection includes rural and urban as well as German- and French-speaking cantons of Switzerland. For the conscription years from 1952 to 1987, only quinquennial average height and weight values from official publications of the Swiss Federal Statistical Office [33–35] exist. Anonymous, individual conscription records from 1992 to 2014 were provided by the Swiss Armed Forces (Logistikbasis der Armee – Sanität, (LBA San)) under contractual agreement with the study authors. The data consisted of date of birth, date of conscription, height, weight, and stage of conscription (NIAx code ‘S’ for first, regular visit versus reassessment).

### *Data Availability and Ethics Statement*

The individual historical data from 1875 to 1879 and 1933 to 1939 were accessed and transcribed in anonymized form from control registers in the Cantonal State Archives after receiving permission to inspect them and completing signed data protection contracts. The data from 1992 to 2014 and the permission to use them are available from the Swiss Armed Forces (LBA San) upon submission and approval of a study protocol. According to the signed bilateral data contract, the Swiss Armed Forces fully anonymized the records by removing all names, social security numbers, and residential addresses prior to delivering the data. Because Swiss conscription is mandatory and the anthropometric measurements used in this study

were nonclinical, government data, informed consent was not required. According to Swiss federal law (Bundesgesetz über die militärischen Informationssysteme (MIG), BG 510.91, Art. 2, 9, 24–29), the Swiss Armed Forces are authorized to make the data accessible in anonymous form for academic research. In the case of analyses based on anonymized and nonclinical government data, additional ethical approval is not needed (Swiss data privacy act, SR 235.1; 19.6.1992 and Federal Act on Research involving Human Beings HRA, 810.30; 1.1.2014) [30, 31].

#### *Data Preparation*

The 1875–1879 dataset initially contained 9,589 conscripts. We excluded four conscripts younger than 18 years, 999 conscripts older than 21 years, 107 conscripts whose height was not recorded, 10 conscripts with a stature below 130 cm, and 955 conscripts whose weight was missing. The cleaned 1875–1879 dataset contained 7,514 conscripts. The 1932–1939 dataset contained 16,163 conscripts after transcription; 8 conscripts younger than 18 years, 595 conscripts older than 21 years, 102 conscripts with missing height, 1 conscript with a stature below 130 cm, and 7 conscripts without a recorded weight were excluded. In the end, the 1932–1939 dataset included 15,450 conscripts. The modern data sample from 1992 to 2014 was delivered containing 877,897 conscripts. We excluded 166 double entries, 6,489 women (who joined the Army voluntarily), 87,074 men with a NIAx conscription status other than ‘S’ (for regular first time appearance), 22 conscripts without a recorded age, 4,537 conscripts younger than 18 years of age, 73,054 conscripts older than 21 years, 26,530 conscripts without a recorded height (all of them before 2004), 45 conscripts below 130 cm, 12 conscripts taller than 215 cm, 23 conscripts with missing weight data, and 7 conscripts lighter than 30 kg. In the end, the modern dataset contained 679,938 conscripts. The overall dataset analyzed in the present study included individual height, weight, and BMI data for 702,902 conscripts aged 18 to 20 years. If we add the more than 241,828 conscripts (no sample size available for 1952) whose height and weight was analyzed and aggregated in the official publications by the Swiss Federal Statistical Office from 1952 to 1987, the total number of conscripts analyzed in this publication totals almost one million.

For the individual data, BMI was calculated as  $BMI = \text{weight (kg)} / \text{height squared (m}^2\text{)}$  and was then categorized using the World Health Organization (WHO) classifications [36]. For the published data from 1952 to 1987, we calculated the average BMI from the average height and average weight (supplementary table S1, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>). Comparisons with the individually calculated BMI of the 1930s and again after 1992 showed that an overestimation of the individually calculated average BMI may have occurred by only 0.02–0.03 kg/m<sup>2</sup> (supplementary table s4, last column, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>). The standard deviation (SD) of the height and weight for the average data from 1952–1987 were estimated from the individual data from the 1930s and early 1990s to calculate the 95% confidence intervals (95% CIs) (supplementary table S1, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>). For the historical data from 1875 to 1879 and 1932 to 1939, we calculated age at conscription in integer numbers as the difference between an individual’s year of conscription and year of birth. The distribution of the age groups (supplementary table S2, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>) showed that until 1939, the large majority of the conscripts (>80%) were 19 years old when measured. For the modern data, we calculated age at conscription from the date of birth and date of conscription and categorized it into three 1-year intervals from 18–19 to 20–21 years of age. The age group distribution showed that for the modern data, the percentage of the 19-year-old conscripts decreased to >45% (still the largest age group), and the proportion of conscripts who were 18 or 20 years old at conscription increased because of the new regulations allowing earlier and later conscription. However, there was a slight tendency towards an older age at conscription for the most recent conscription years (mean age at conscription was 19.0 years in 1994 versus 19.3 years in 2014).

#### *Representativeness*

Earlier studies on similar datasets have suggested that the register books for 1875–1879 contain nearly complete birth cohorts [32, 37] and that the modern data has maintained high coverage (>95% of the living young Swiss men) [30]. The 5% in absentia exemptions were not restricted to short or obese young men only but covered the full range of chronic diseases and physical and psychological disabilities not necessarily related to height or weight [38].



### Statistics

We primarily used descriptive statistics (means with 95% CIs, medians, SDs, skewness etc.) to analyze the data as well as graphical methods (kernel density estimations and quantile-quantile plots) to observe changes in the shape of the distributions. Because of the large size of the dataset, only minimal methods (two sample t-tests with equal variance) were applied to test the differences between means. In the case of the BMI-to-height relationship, we applied local polynomials to smooth the BMI means from the full height scatter plots. In order to numeralize this relationship and similar to other studies [20, 21], we additionally performed a linear regression with 10 cm height categories as dummy variables to model the changes over time. All of the analyses and graphs were performed using Stata (version 13; Stata Corp., College Station, TX, USA).

## Results

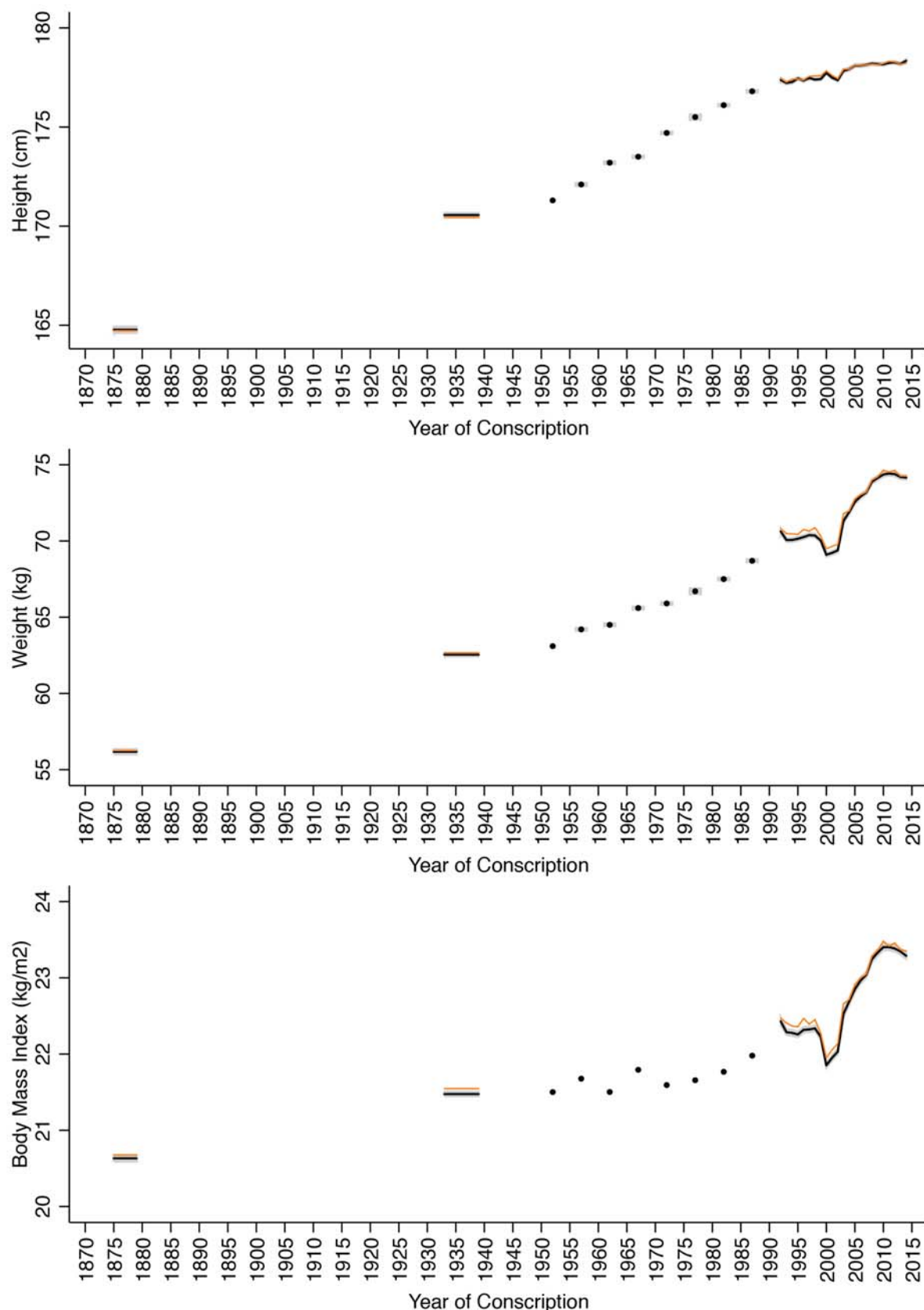
Over the 135 years of observation, Swiss conscripts became on average significantly taller by 13.57 cm (95% CI 13.40–13.74 cm;  $t(40485) = 100$ ;  $p = 0.0000$ ), from 164.78 cm (95% CI 164.62–164.94 cm) in 1875–1879 to 178.35 cm (95% CI 178.28–178.42 cm) in 2014. The average weight increased by a total of 17.99 kg (95% CI 17.68–18.29 kg;  $t(40485) = 110$ ;  $p = 0.0000$ ) from 56.17 kg (95% CI 56.00–56.34 kg) in 1875–1879 to 74.16 kg (95% CI 74.02–74.30) in 2014. Consequently, the average BMI also significantly increased by 2.66 kg/m<sup>2</sup> (95% CI 2.57–2.75 kg/m<sup>2</sup>;  $t(40484) = 59.34$ ;  $p = 0.0000$ ), from 20.63 kg/m<sup>2</sup> (95% CI 20.59–20.67 kg/m<sup>2</sup>) in 1875–79 to 23.29 kg/m<sup>2</sup> (95% CI 23.25–23.33 kg/m<sup>2</sup>) in 2014 (supplementary table S4, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>).

These trends were not linear. The average height increased by 1.9 cm per decade between the 1952–1962 conscription years, by 1.5 cm per decade between 1962 and 1972, by 1.4 cm per decade between 1972 and 1982, and by 1.3 cm between 1982 and 1992 (birth years 1963–1973). After the 1970s birth years, the positive height trend markedly slowed (0.0 cm increase per decade between the 1992–2002 conscription years and 0.9 cm per decade between 2002 and 2012). In contrast to height, the trend in average weight – which for a long time increased in parallel with height (supplementary fig. 1, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>) – did not slow up in recent decades but increased in two strong steps, one at the end of the 1980s conscription years and again after 2002. These height and weight changes were reflected in the average BMI, which was stable during the second half of the 20th century and then mirrored the two large increases in weight approximately 1990 and after 2002 (fig. 1). During the last 3–4 conscription years after 2010, the average BMI no longer increased but stabilized on a high level. An age sensitivity test showed that the observed pattern was stable for the 19-year-old conscripts only (the largest age group) (fig. 1).

Not only did the averages change over time, but the shape and the position of the distributions did as well. Height, which was slightly left-skewed (–0.35) in the 1875–1879 data, mainly shifted upwards on the x-axis over time and was symmetrically distributed (fig. 2, left side). In contrast, weight and BMI – also almost symmetrically distributed in 1875–1879 and 1933–1939 – became increasingly right-skewed in 1994 and 2014 (supplementary table S4, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>). Although the lower end of the BMI distribution hardly changed between the 1930s and 1994; the upper quantiles became increasingly higher (fig. 2, right side).

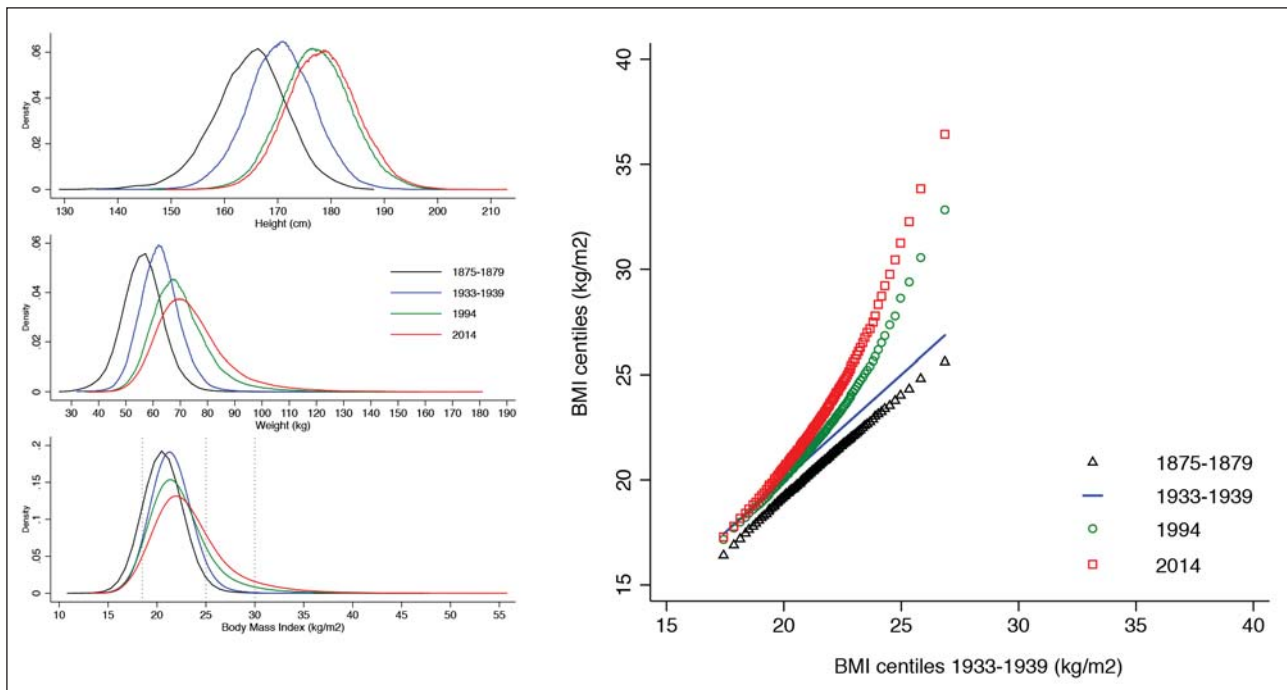
Accordingly, the prevalence of underweight, overweight, and obesity changed. From 1875 to 1879, 12.1% of the conscripts were underweight (BMI < 18.5 kg/m<sup>2</sup> by modern WHO definition) at conscription, whereas overweight (1.6%) and obesity (0.1%) were barely prevalent (supplementary table S3, available at <http://content.karger.com/ProdukteDB/produkte.asp?doi=446966>). From 1933 to 1939, 91.3% of the conscripts had a normal weight, under-

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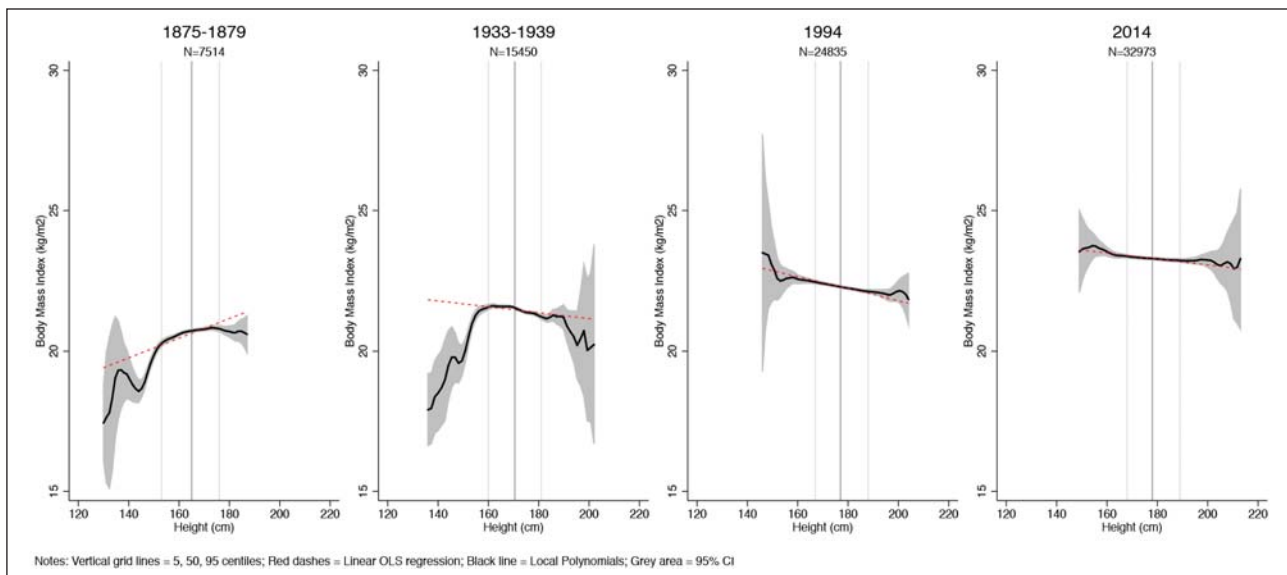


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**Fig. 2.** The change in the height, weight, and BMI distributions over time (left graph) and a Quantile-Quantile (QQ) plot of the BMI distributions from 1875–1879, 1994, and 2014 against the 1933–1939 distribution to illustrate the change in shape at the upper tails of the modern distributions (right graph).



**Fig. 3.** The shift in direction of the mean BMI-to-height relationship over time. Smoothing method = Local Polynomials, Grey area = 95% CIs, red dashed line = linear regression line, vertical grid lines = 5th, 50th, and 95th height percentiles.

**Fig. 1.** The change in average height, weight and BMI for 18- to 20-year-old young men in Switzerland between 1875–1879 and 2014. Grey areas = 95% CIs, orange line = sensitivity analysis: 19-year-old conscripts only, 1952–1987 = published data only.



weight was reduced to 4.9%, and only a total of 3.8% had a BMI  $\geq 25.0$  kg/m<sup>2</sup>. In 1994, after the first large increase in average BMI, the prevalence of overweight had increased to 11.8% and obesity to 2.5%. Finally, between 1994 and 2014, overweight was multiplied by a factor of 1.56 to 18.4% and obesity by a factor of 2.28 to 5.7%. Overall, a total of 24.1% of the young men appearing at conscription in 2014 had a BMI  $\geq 25$  kg/m<sup>2</sup>.

The BMI-to-height relationship changed direction over time (fig. 3). In 1875–1879, the relationship was positive between the 5th and the 90th percentiles (the taller the conscripts, the higher their BMI). The relationship was stable for the conscripts above the 90th height percentile (no higher BMI). For the very short conscripts below the 5th height percentile, the positive BMI-to-height relationship became even more pronounced; they were not only very short but also very slim. From 1933 to 1936, the general direction of the BMI-to-height relationship changed direction and was negative above the 5th height percentile (the taller the conscripts, the lower their BMI). In contrast, very short conscripts below the 5th height percentile were still significantly slimmer. In 1994 and 2014, the general BMI-to-height relationship stayed negative, but the double burden (very short conscripts also being very slim) at the lower end of the height distributions had disappeared. The linear regression confirmed the direction and the significance of the coefficients (table 1).

## Discussion

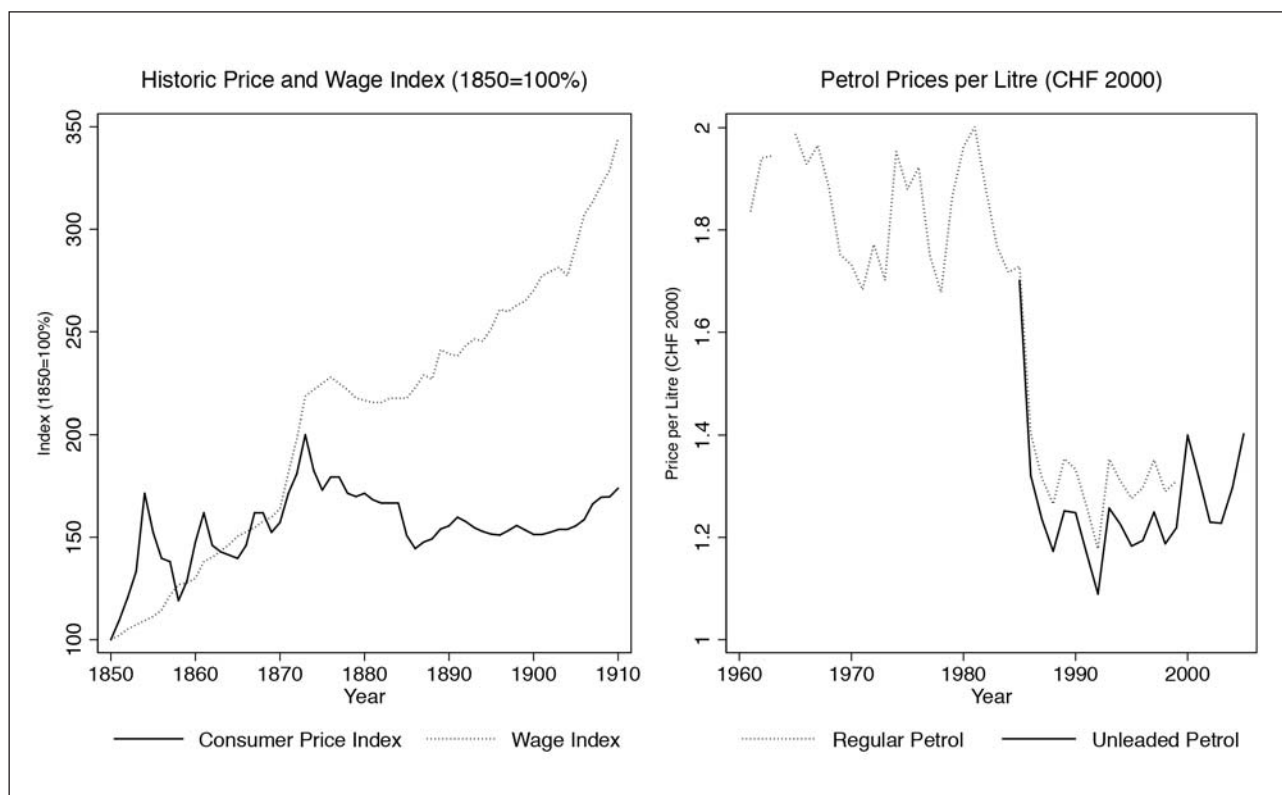
This study analyzed the most recent anthropometric data available from mandatory conscription in Switzerland from 1992 to 2014 and incorporated it into the historical context from 1875 to 1879 to assess temporal changes. In general, Swiss conscripts changed their growth pattern from first growing in length to then growing mainly in width. Over the 135 years analyzed, Swiss conscripts became significantly taller by an average of 13.57 cm, from 164.78 cm in 1875–1879 to 178.35 cm in 2014. This increase in average height started in the 1870s birth years and markedly slowed after the 1970s birth years. In contrast to height, the increase in average weight did not decelerate during the last two to three decades but increased in two distinct periods at the end of the 1980s and again after 2002. The weight and BMI distributions became increasingly right-skewed, and the share of overweight and obese young men increased to 18.4% and 5.7%, respectively, in 2014. From 1875 to 1879, the BMI-to-height relationship was positive (the taller the conscripts the higher their BMI), and very short conscripts were also very slim, indicating a double burden of undernutrition.

The positive trend in average height in general and among the Swiss conscripts in particular has been well documented [38, 39]. Among other clustering co-factors (positive assortative pair mating, epigenetics), greatly improved living conditions (nutrition, disease environment, and physical workloads) may be primarily responsible for the secular height trend [40, 41]. During the 1870s, when the positive trend started, the Swiss railway system became international, allowing authorities to balance the shortages in food supply by importing cheap mass products [42]. Consequently, the historic price index became more stable and less volatile, while the historic wage index continued to increase (fig. 4, left side) [43]. As a result, real wages increased, more money was available to families for nutrition, and the daily per capita caloric intake increased from 2,601 kcal in 1870 to 3,041 kcal in 1912 [44]. In recent decades, the rate of increase in height has markedly slowed in Central and Northern Europe. The current consensus in the literature is that because of the Central and Northern European countries' stable environments, the genetic endpoint of the population has been reached at a mean level of 178–180 cm [39, 45].

The relatively strong left-skewness of the height distribution (short men being overrepresented) and the 12.1% prevalence of underweight young men at conscription in the late

**Table 1.** Linear regression results of BMI per height category

Height category	1877					1936					1994					2014				
	N	coef.	SE	P> t		N	coef.	SE	P> t		N	coef.	SE	P> t		N	coef.	SE	P> t	
130-139	16	-1.02	0.49	0.036		5	-3.58	0.86	<0.001											
140-149	142	-2.14	0.17	<0.001		27	-2.16	0.37	<0.001		2	-0.88	2.15	0.684		1	1.02	3.77	0.787	
150-159	1409	-0.35	0.06	<0.001		631	-0.27	0.08	0.001		88	-0.06	0.33	0.859		68	0.43	0.46	0.347	
160-169	4131	reference				6,033	reference				2667	0.18	0.06	0.005		2,632	0.14	0.08	0.080	
170-179	1,712	0.1	0.06	0.067		7,567	-0.17	0.03	<0.001		13,152	reference				16,155	reference			
180-189	104	0.04	0.19	0.825		1,153	-0.42	0.06	<0.001		8,110	-0.18	0.04	<0.001		12,588	-0.06	0.04	0.174	
190-199						32	-1	0.34	0.003		803	-0.4	0.11	<0.001		1,481	-0.08	0.1	0.460	
>200						2	-1.42	1.36	0.298		13	-0.95	0.84	0.260		47	0.09	0.55	0.868	
cons		20.72	0.03	<0.001			21.61	0.02	<0.001			22.33	0.03	<0.001			23.3	0.03	<0.001	
N	7,514					15,450					24,835					32,972				
R-squared	0.0277					0.0073					0.0018					0.0002				
Adj R-sq	0.0271					0.0069					0.0016					0.0001				



**Fig. 4.** Swiss historic consumer price and wage index from 1850–1910 (left graph, (1850 = 100%, source: SWISTOVAL [43, 46, 61])) and deflated prices (CHF from 2010) for regular and unleaded petrol in Switzerland from 1977–2005 (right graph, source: Swiss Federal Statistics [62, 63]).

19th century both indicate that malnutrition was common at the eve of the secular height trend [38]. This may be one of the causes of the positive BMI-to-height relationship and the dual burden of malnutrition (both short and thin) at the lower end of the height distribution in the 1875–1879 conscripts. That the tall 5% conscripts did not have higher BMI values may be explained by the fact that it may have been more difficult for taller people to obtain enough calories [21]. The relatively low living standard in Switzerland is also reflected in having real wages that were lower than those of other European countries at the end of the 19th century [46]. It was only until the First World War when Switzerland witnessed less volatile prices and matched the height and wage level of other countries in Central Europe [38]. Until the conscription years in the 1980s, average height and weight increased in parallel.

This study adds to the literature that the obesity epidemic in Switzerland started at the end of the 1980s, proceeded in two strong upward steps, and stabilized in the last 3–4 conscription years. The first upward step at the end of the 1980s coincided with the introduction of American fast food restaurants [47, 48] and a marked price reduction of fuel in Switzerland (fig. 4, right side); this suggests that the nutritional and physical activity patterns may have changed during that period. The most recent high-level BMI stabilization mirrors the results from recent studies on Swiss schoolchildren [49].

The deviation from 2000 to 2002 in conscripts' average weight and BMI cannot currently be explained. Further tests have shown that the entire weight distribution was affected. The medical service of the Swiss Armed Forces ensured that the measurement standards (calibrated scales, cantonal sample composition, sample size etc.) did not change during the 3

years under question. Potential explanations must be sought either regarding the data (artifact etc.) or regarding environmental factors (at the time of birth or conscription); however, no explanations are known at the moment. Furthermore, no dataset from other Swiss sources or from conscription in neighboring countries can be used for comparison because of their lack of annual precision.

The phenomenon of the stabilizing secular height trend and the incipient obesity epidemic can also be observed 30 years earlier in the USA [19, 50]. The levels of obesity (BMI  $30 \text{ kg/m}^2$ ) among conscripts in 2010 and 2011 were slightly lower in Switzerland (5.8%) compared to other European countries with mandatory conscription (Germany 8.5%, Denmark 8.7%, and Austria 8.4%) [51, 52].

From the evolutionary perspective, our results are compatible with a plastic human growth and weight change response to changing environmental conditions. These results are consistent with hypotheses on fetal programming [53], epigenetic effects on the genotype [54], and transgenerational maternal effects [55]. Our data do not enable the distinction between these developmental mechanisms, and further studies are needed to investigate this point. However, we did confirm that short-term adaptations in humans can occur. Specifically, we showed how the bodies of young men adapted differently to opposing living conditions in Switzerland, with less investment in height and weight under conditions of undernutrition, an investment in increasing height under more stable nutritional conditions, and an increase in weight and the development of obesity under conditions of overnutrition and decreasing physical activity.

The present study has several limitations. First, it reflects the changes in body shape of 18- to 20-year-old men with Swiss citizenship only. Second, the data did not allow for the controlling of the migration background of the young men. Third, the cantonal coverage of the historical data is incomplete because of the limited control book survival in the archives. Fourth, government authorities decided not to measure weight between 1880 and 1931, causing a weight gap in the time series for these years. Fifth, the quality of the recent data from 1992 to 2003 may be slightly limited, which is reflected in the relatively high number of missing height values before 2004 and the mysterious discontinuity in the weight distribution from 2000 to 2002. Sixth, the primary group of 19-year-old young men became relatively less important over the observed cross-sections, and the share of 20-year-old conscripts increased in recent years. However, similar studies have demonstrated that the different age groups typically show identical height and BMI patterns [30, 39]. Seventh, we are aware of the difficulty in using contemporary WHO categories for BMI as a framework for historical data, as health-relevant risk cut-off points in BMI may have shifted over time [56]. Eighth, BMI is generally limited as indicator for body shape, and technical studies are still debating on the most adequate way of relating body height and weight [57–60]. Ninth, we cannot control for the fact that delayed physical growth may also be an explanatory factor. The gap in physical development between healthy young men who achieved their final height by the age of 19 and those who continued to grow after 19 until their mid-20s was certainly wider in the 19th century than it is today [38]. Moreover, socioeconomic factors may play a critical role in explaining the changes in BMI, as suggested by earlier studies [32]. Future studies should thus focus on the differences between groups from different socioeconomic positions within the presented anthropometric patterns to investigate potential confounding factors.

We presented secular trends in height and weight in Swiss conscripts from the late 19th century to today and showed an increase over time in first height and later in BMI under improving nutritional conditions. Our results can be seen as an example of human developmental plasticity. The changes in the environmental conditions observed in this study are currently occurring in different regions of the world, and our data predict that similar changes in height and weight may occur in these transitional regions either now or in the near future.

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